The Coyote Unmanned Aircraft System:

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Advancing the Technology Readiness of Low Altitude Expendable UAS Observations in Hurricanes to Address Critical Data Gaps, Improve Understanding and Enhance Future Forecasts of Intensity Change

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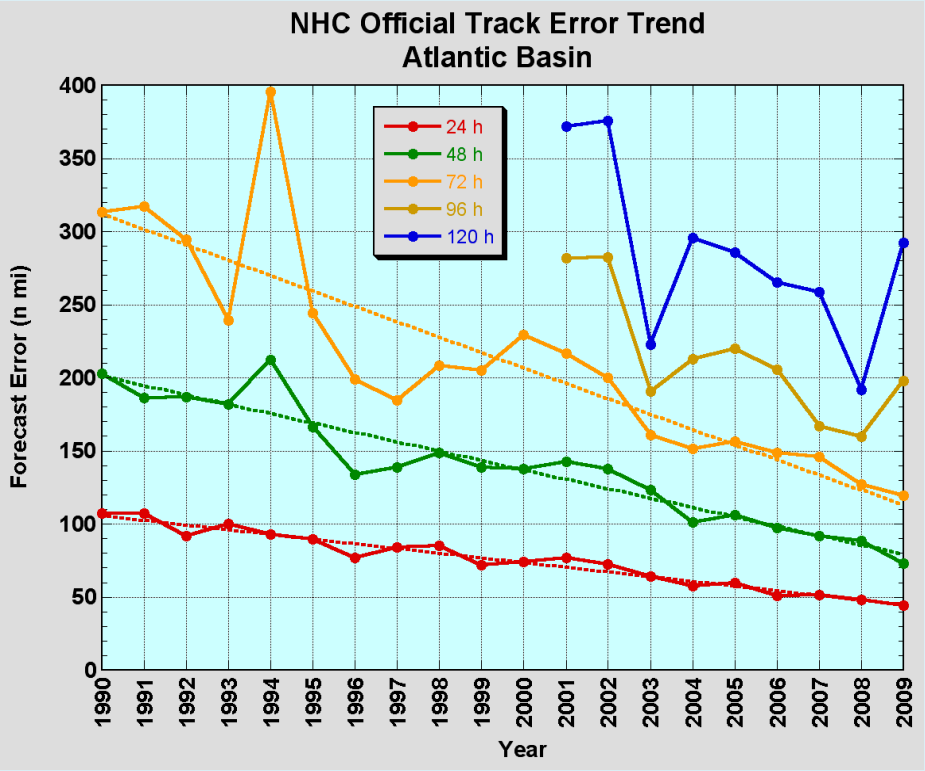
Coyote Unmanned Aircraft System

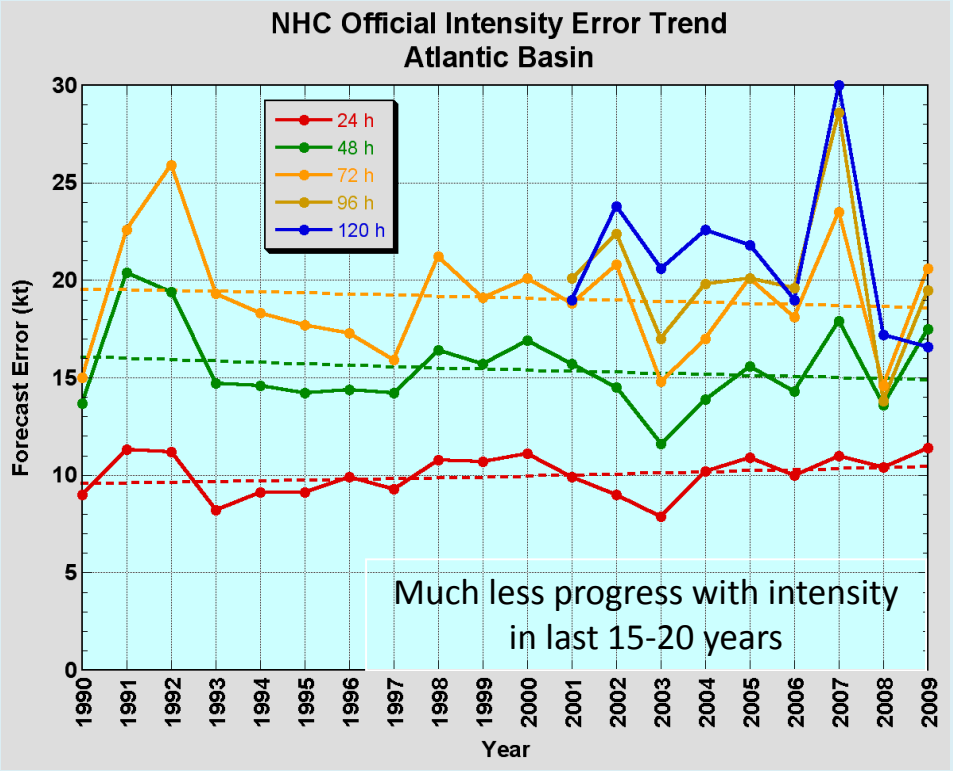
Project Motivation: Long-term forecast trends…

Track forecast improvements



- Errors cut in half over past 15 years
- 15-year improvement - As accurate at 48 hours as we were at 24 hours in 1999

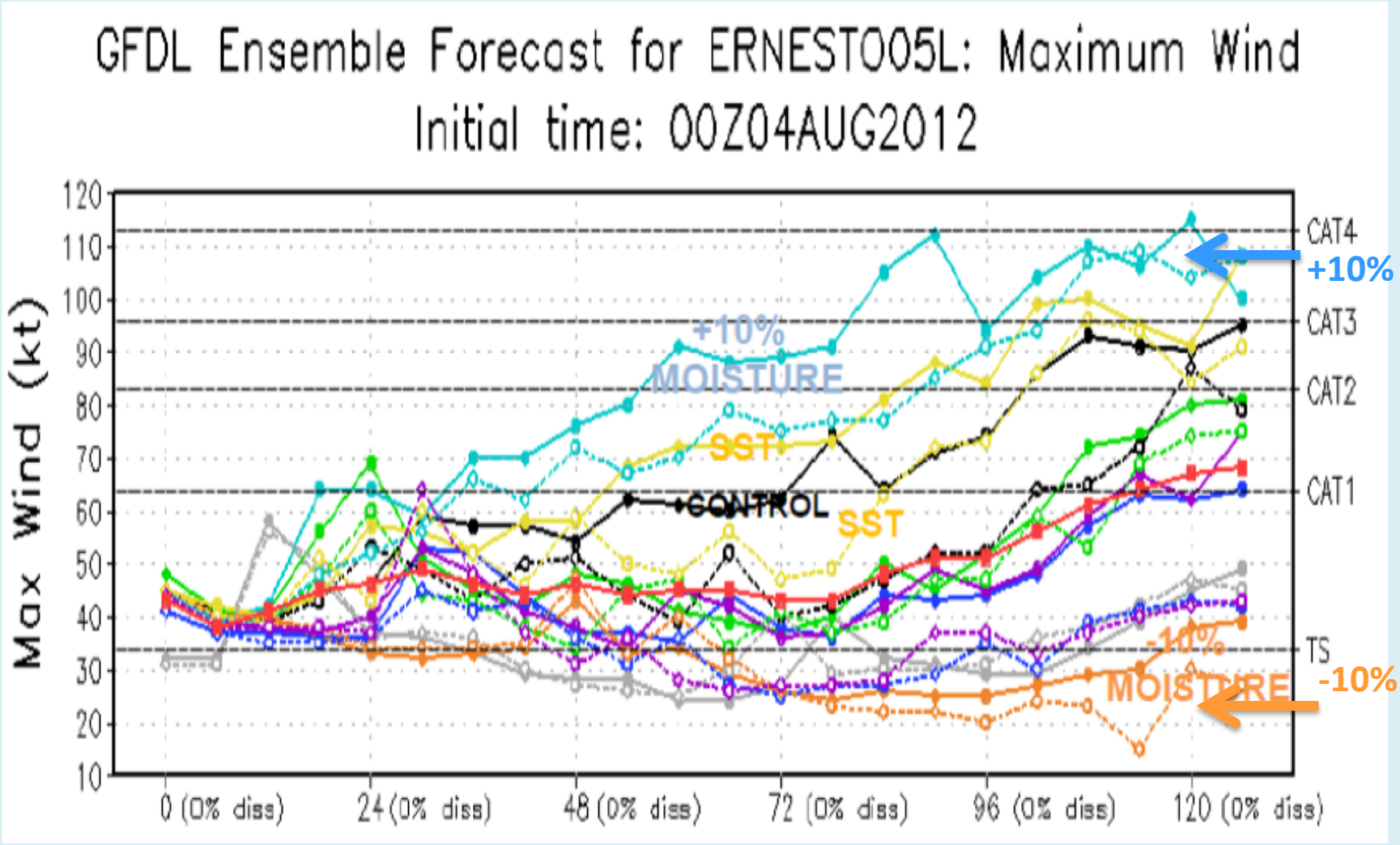
Intensity forecast improvements



- 24-48h intensity forecast off by 1 category
- Off by 2 categories perhaps 5-10% of time

Coyote Unmanned Aircraft System

Today's Models Exhibit Extreme Forecast Sensitivity to Small Differences in Boundary Layer Moisture



Coyote Unmanned Aircraft System

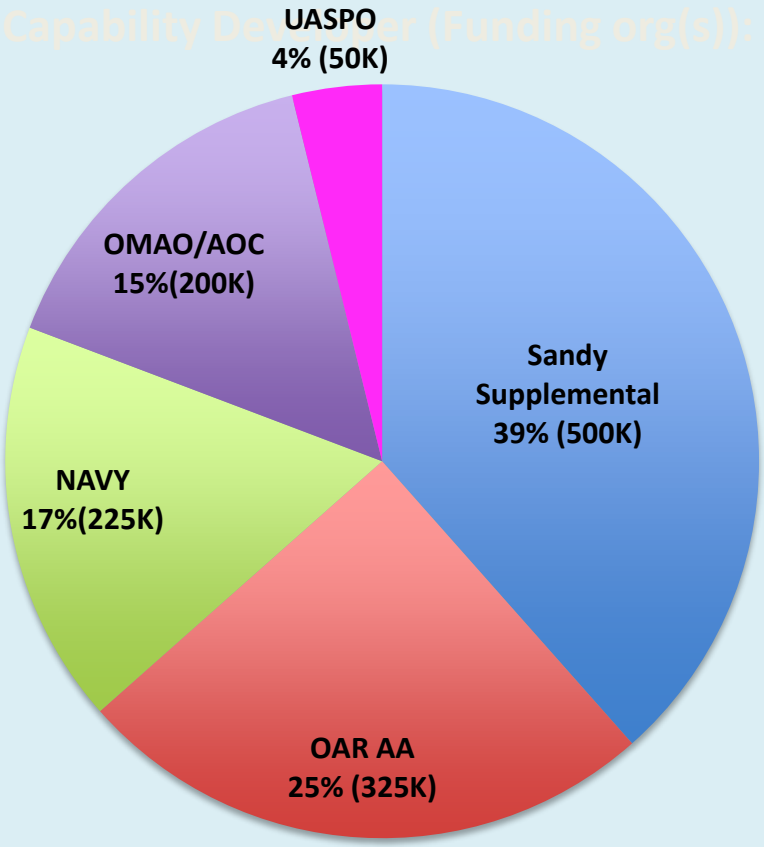
Partnerships in Development of the Platform:

- NOAA HRD (PI, PM, Turbulence Research)
- NOAA OMAO/AOC (Co-PM, R&D P-3 testing and ops support)
- NOAA AOML (OSE, OSSE)
- NOAA ARL (Payload Testing and Development)
- NOAA PSD (AI software, Sensors)
- NCAR/EOL (Small Sensors, Turbulence and Communications)
- NCAR/MMM (Fine Scale/LES Simulations, Process Studies)
- UWyo (Turbulence R&D)
- Raytheon (Project Integration, other IRAD support)

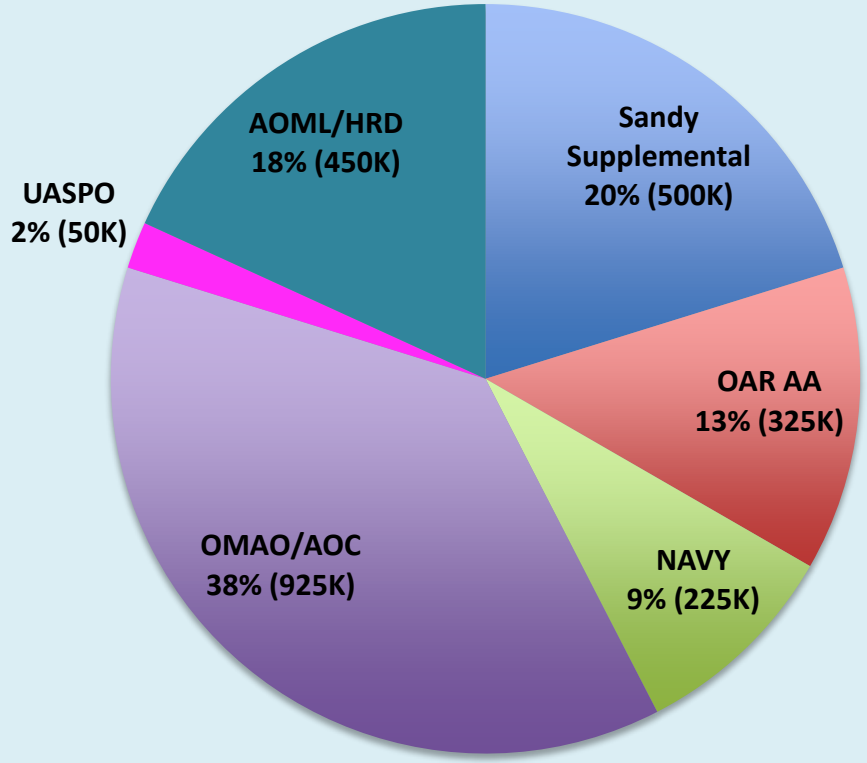
Coyote Unmanned Aircraft System

- Capability Name: *Coyote UAS (Raytheon Corp)*
- Capability Developer (Funding org(s)): *Advancing Coyote to ~ TRL7+ ('16)*

Coyote Funding 2014-16 ($1.3M)



Coyote Funding 2014-2016 w/FTE and 50 flight hours ($2.475M)



Coyote UAV

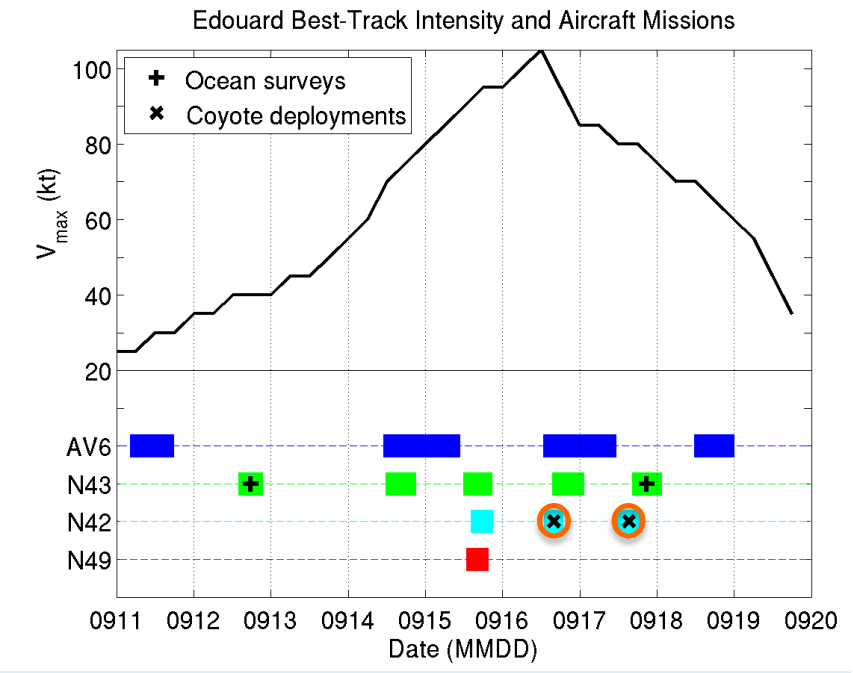
- Coyote is a canister launched, unmanned air vehicle (UAV)
- Specs and capabilities:
  - Airspeed: 55 kts cruise, 70 kts dash
  - Deployment altitude: up to 30,000 ft MSL (in non-icing conditions)
  - Comms range: 50nmi (May 2016); 70nmi (ground test October 2016)
  - Endurance: 1 hr+ @ cruise (May 2016); 2h (2017)
  - Weight: 13 lbs
- Developed in 2004 (Navy/SBIR) to augment manned aircraft capabilities
- UAV is stored and deployed similar to current dropsondes & sonobuoys
  - Sleeve discarded and flight surfaces deployed ~ 5-20 secs
  - GPS and autopilot initiated ~ 10 secs
  - Chute discarded after approximately 15-30 seconds
- UAV flight duration approximately 60 minutes
  - Extend aircraft time on-station
  - Extend aircraft sensor range and coverage
  - Provide extended horizontal profiling at low altitude
  - Increase aircraft and crew survivability

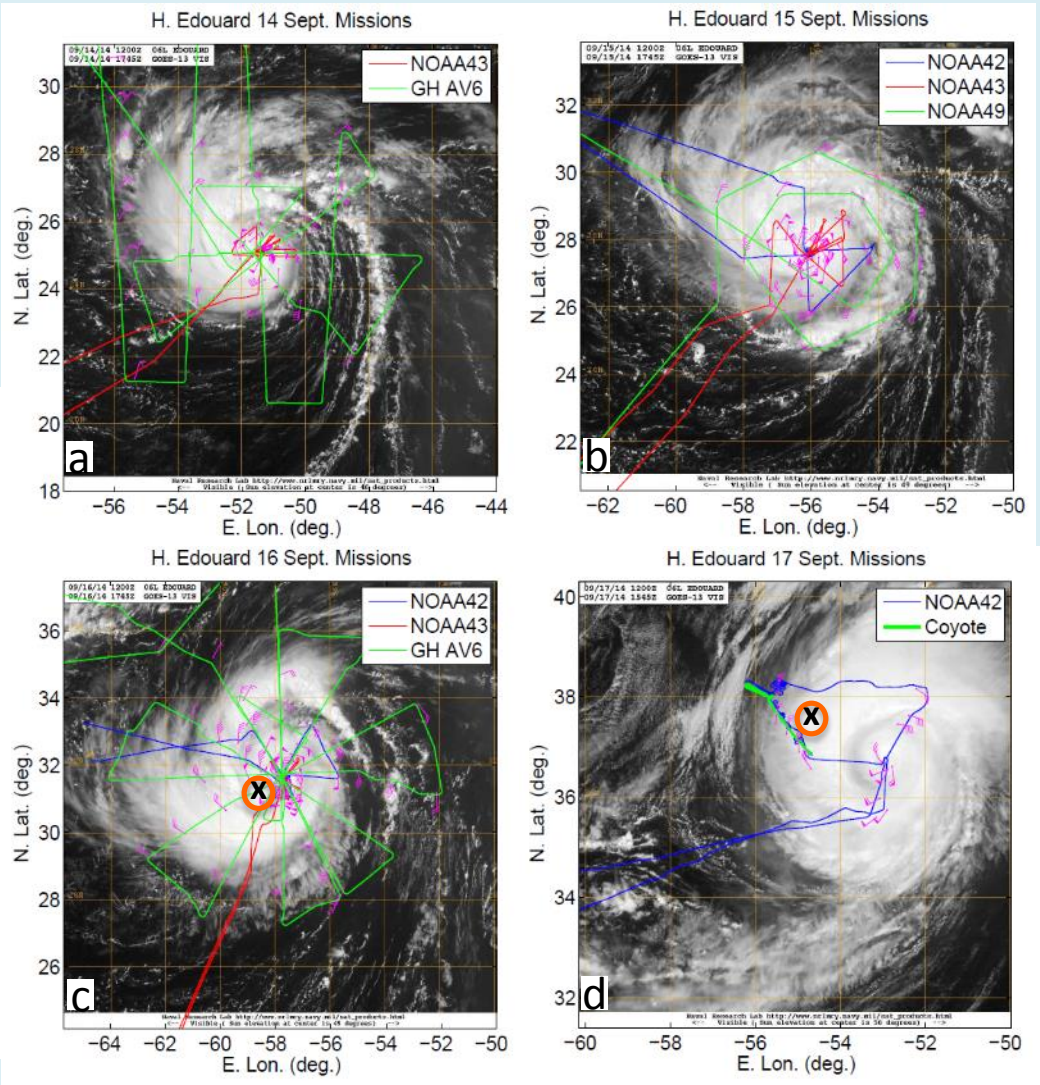
Coyote UAV – Deployment Sequences

Coyote UAV – Deployment Sequences

The 2014 deployment into Hurricane Edouard

- Aircraft based at:
  - St Croix (P-3 N43)
  - Bermuda (P-3 N42, G-IV N49)
  - Wallops Is. (GlobalHawk AV6)



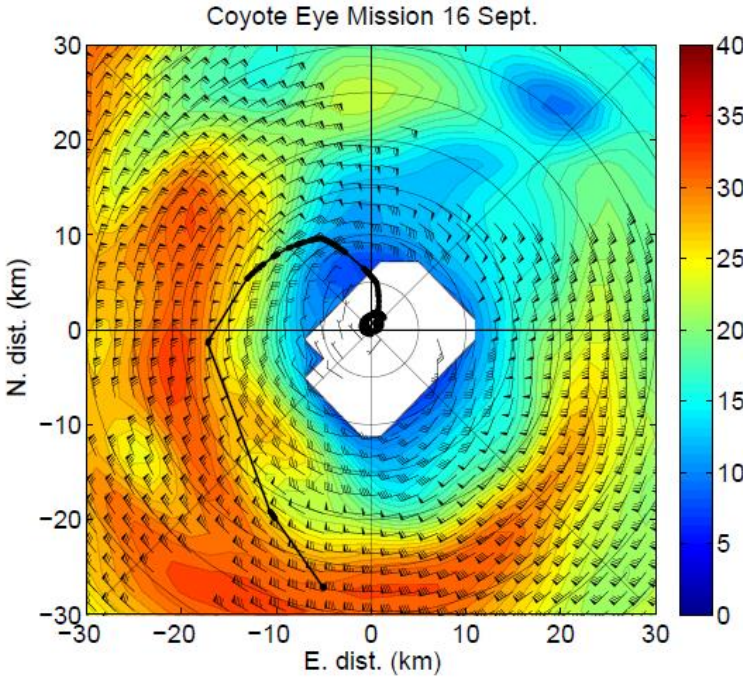


First Air-Deployed UAS Flight into a Hurricane

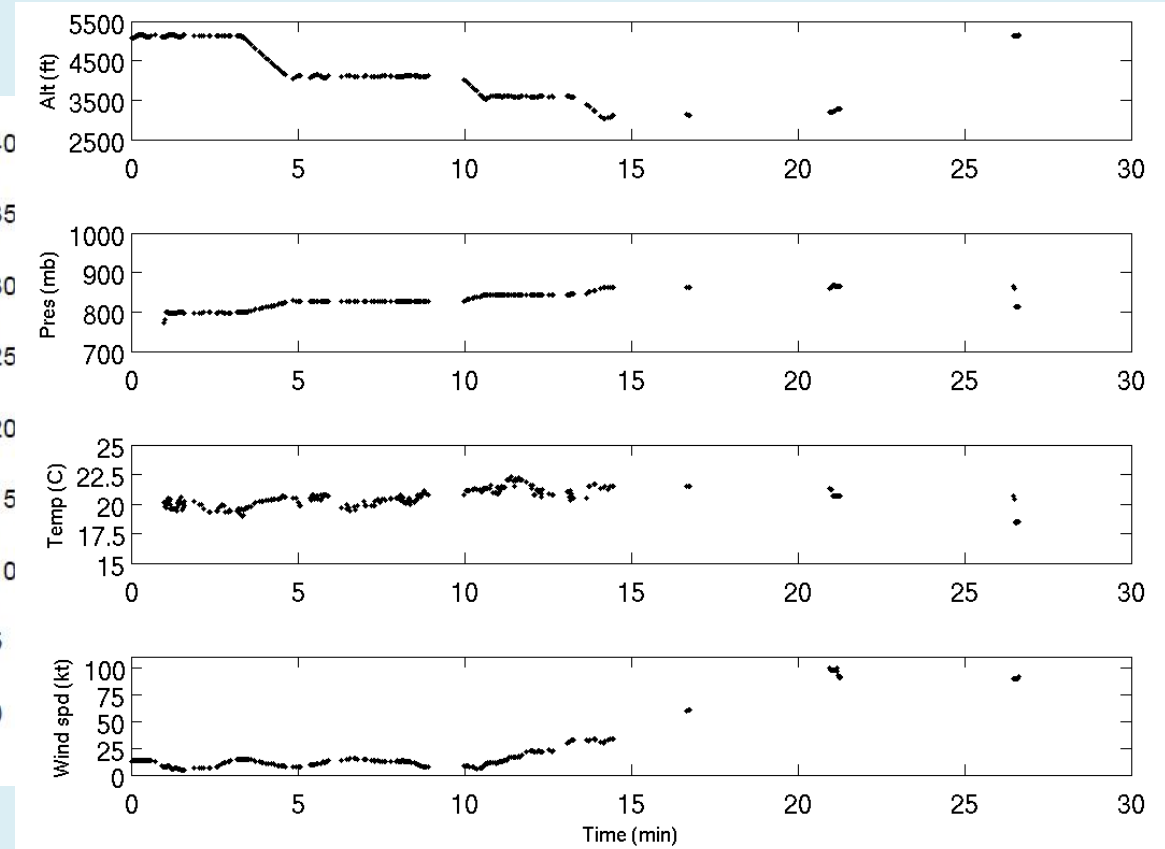
When: 1432Z September 16th 2014
Where: Deployed into Major Hurricane Edouard's eye (then eyewall)
Deployment aircraft: NOAA WP-3D Orion (42)
UAS flight duration: 28 minutes
Minimum Altitude: 896m
Maximum Wind Speed: 100kt @971m (in SW eyewall) Platform record!

Coyote Eyewall Penetration

- Dropped at 5000 ft. altitude in eye
- P-3 loitered in eye for maintaining comms; became spotty as Coyote entered eyewall due to P-3/UAS range limitations
- Measured 100 kts winds



Coyote flight track;
1km tail Doppler radar winds
and reflectivity



Circling in eye

Enter eyewall

Max winds

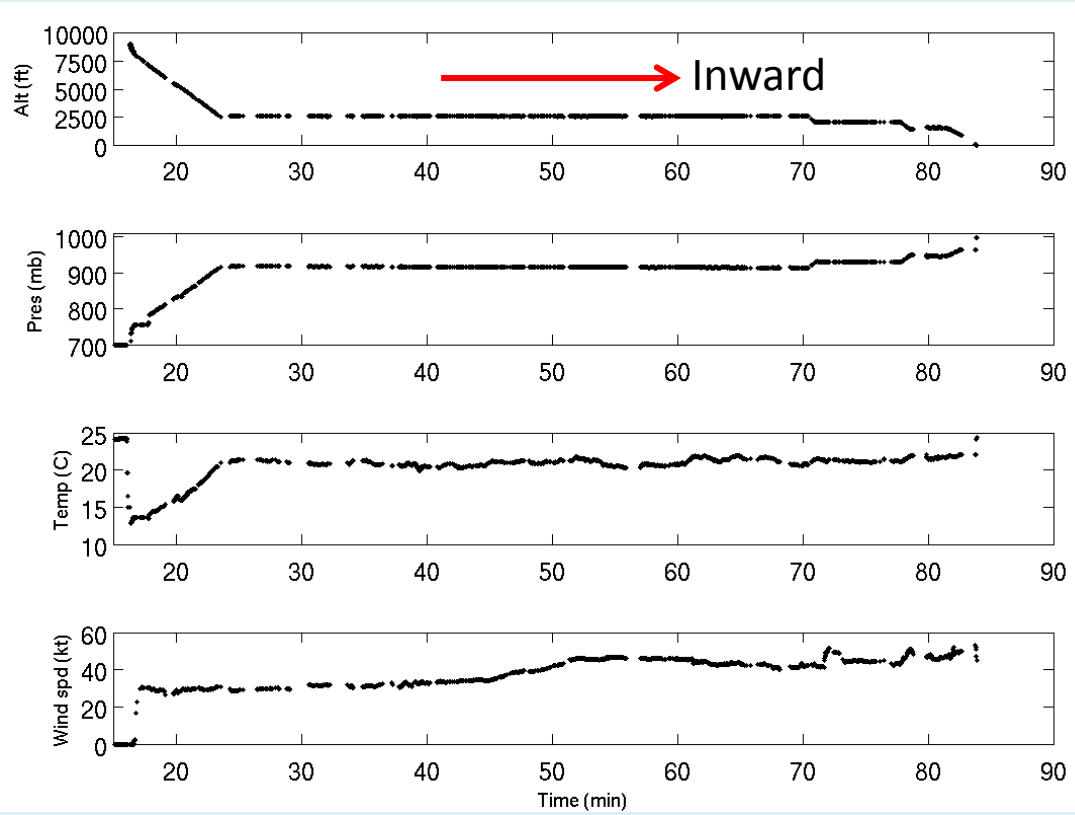
Record duration Coyote UAS mission

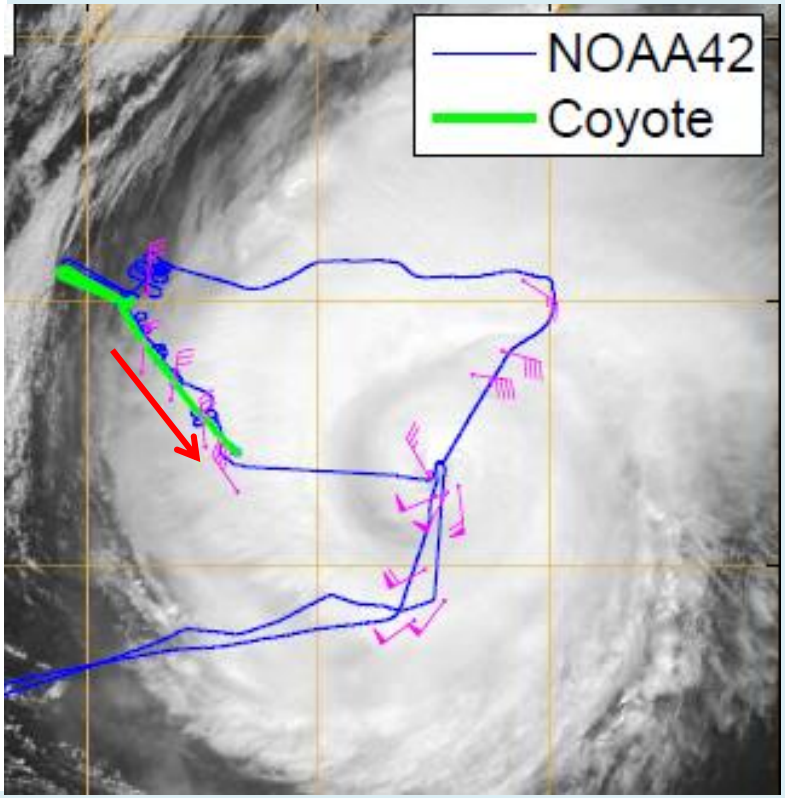
Thermodynamic and kinematic radial profile within the boundary layer of Hurricane Edouard

When: 1507Z September 17th 2014
Where: Deployed along Hurricane Edouard boundary layer inflow channel
Deployment aircraft: NOAA WP-3D Orion (42)
UAS flight duration: 68 minutes (platform record!)
Minimum (controlled) Altitude: 400m
Maximum Wind Speed: 53kt @6m

Coyote BL Inflow Mission

- Dropped at 10000 ft. altitude ~140 nm NW of storm center
- Descended to 2500 ft. traveling outward, then reversed course flying inward
- Maintained altitude for ~50 min, then began stair-steps toward surface as P3- “followed” (good coms throughout)
- Ditched after ~65 min of flight ~90 nmi west of center





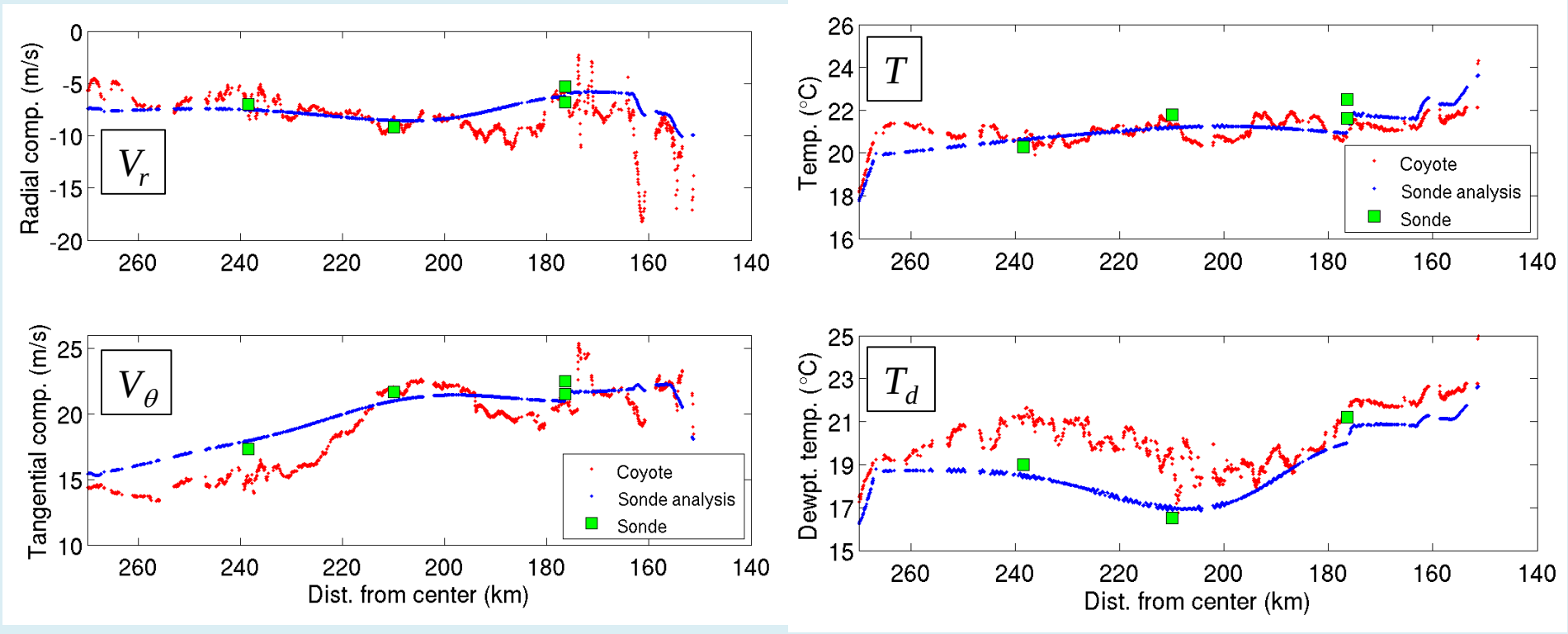
Validation of Coyote Observations: *September 17th Inflow Experiment*

As of 10/3/2016…peer review publication in AGU's Earth and Space Science

DOI - 10.1002/2016EA000187

http://onlinelibrary.wiley.com/doi/10.1002/2016EA000187/full

- As autlined in the AGU manuscript, The Coyote UAS data compare very well with nearly collocated dropsonde measurements at the same altitude
- Also, data are contrasted with an analysis of GPS Dropsonde measurements
  - Weighted-mean interpolation to Coyote location



Validation of Coyote Observations: *Sept 16th Eye/Eyewall Experiment*

FIG. 3

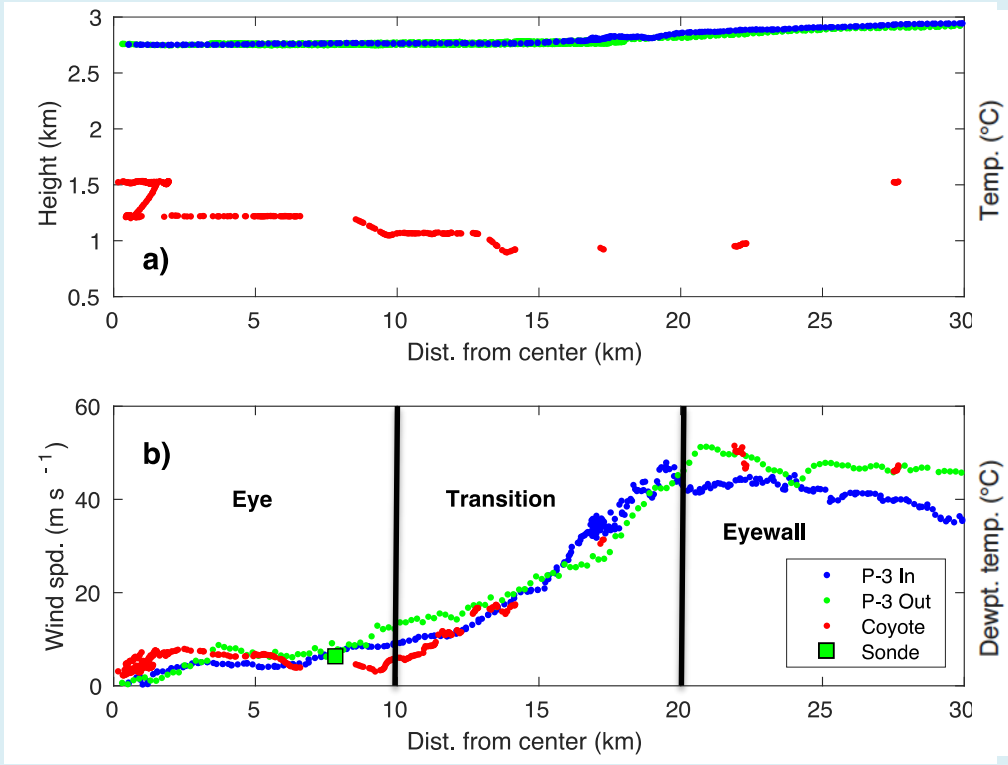


FIG. 4

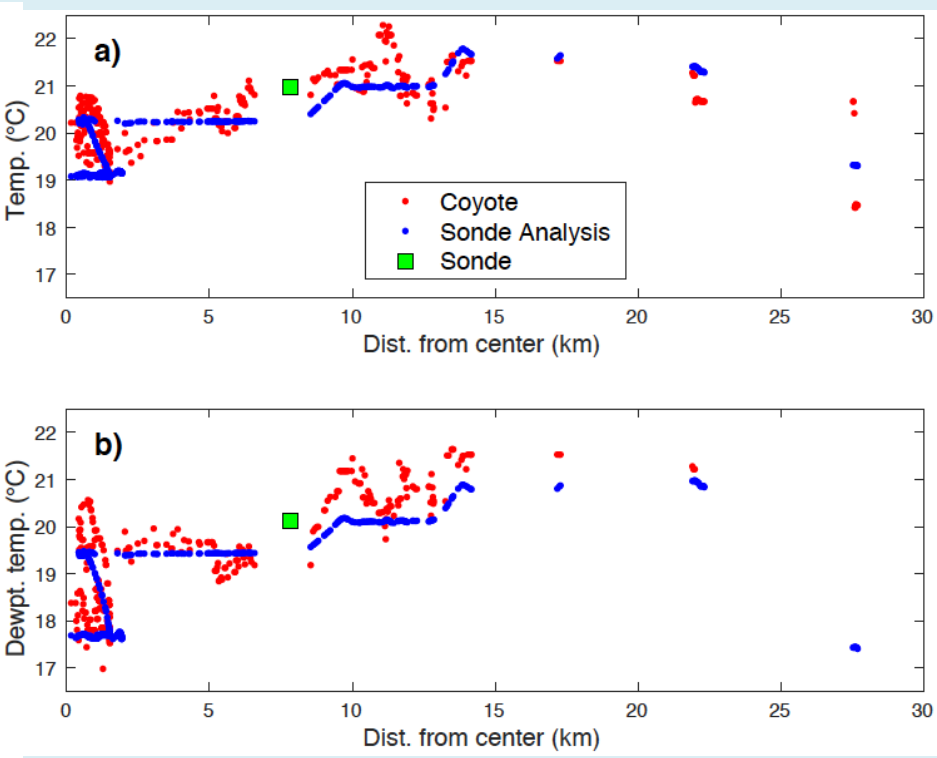


FIG. 3. a) Flight altitude and b) wind speed measured with respect to radial distance for the Coyote (red) and the WP-3D inbound (blue) and outbound (green) legs during the 16 Sept 2014 mission. The green square indicates a measurement made by a dropsonde located 16 km from the Coyote.

FIG. 4. a) Air temperature and b) dew point temperature measured by Coyote (red) and from an analysis (blue) of dropsonde measurements for the 16 Sept 2014 Coyote flight. Green squares indicate measurements made by a dropsonde located 16 km from the Coyote.

Coyote Unmanned Aircraft System

- The Coyote UAS is a mature in-situ and remote sensing technology designed for use from the P3 in dangerous, intense environments such as hurricanes.

- The data gathered in 2014 during the major Hurricane Edouard campaign compares well with dropsonde and select P3 eyewall penetration data.

- **Key capabilities progressing from advanced R&D (now) to operations (future):**
  - Ability to sample for hours (vs minutes as with GPS dropsonde)
  - Ability to sample an area/volume vs. GPS sparsely sampled vertical profiles
  - Expected final operations will use existing GPS dropsonde infrastructure

    (AOC personnel with existing AVAPS data/communication system)
  - At the operational stage, the UASonde payload is expected to include high quality measurements of PTHU ($\geq$4hz), SST and 3D wind-capable turbulent quantities. Today's GPS dropsonde sensors provide measurements of PTHU (@2-4hz).
  - Cost (using a data/min metric) expected to be lower than existing GPS cost, while simultaneously providing enhanced data coverage and capabilities

- ***Next step: Explore developing the next generation hybrid "UASsonde" system in an effort to help NOAA (and the many global other AVAPS users) to better meet existing (and potentially new) research and operational requirements.***

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